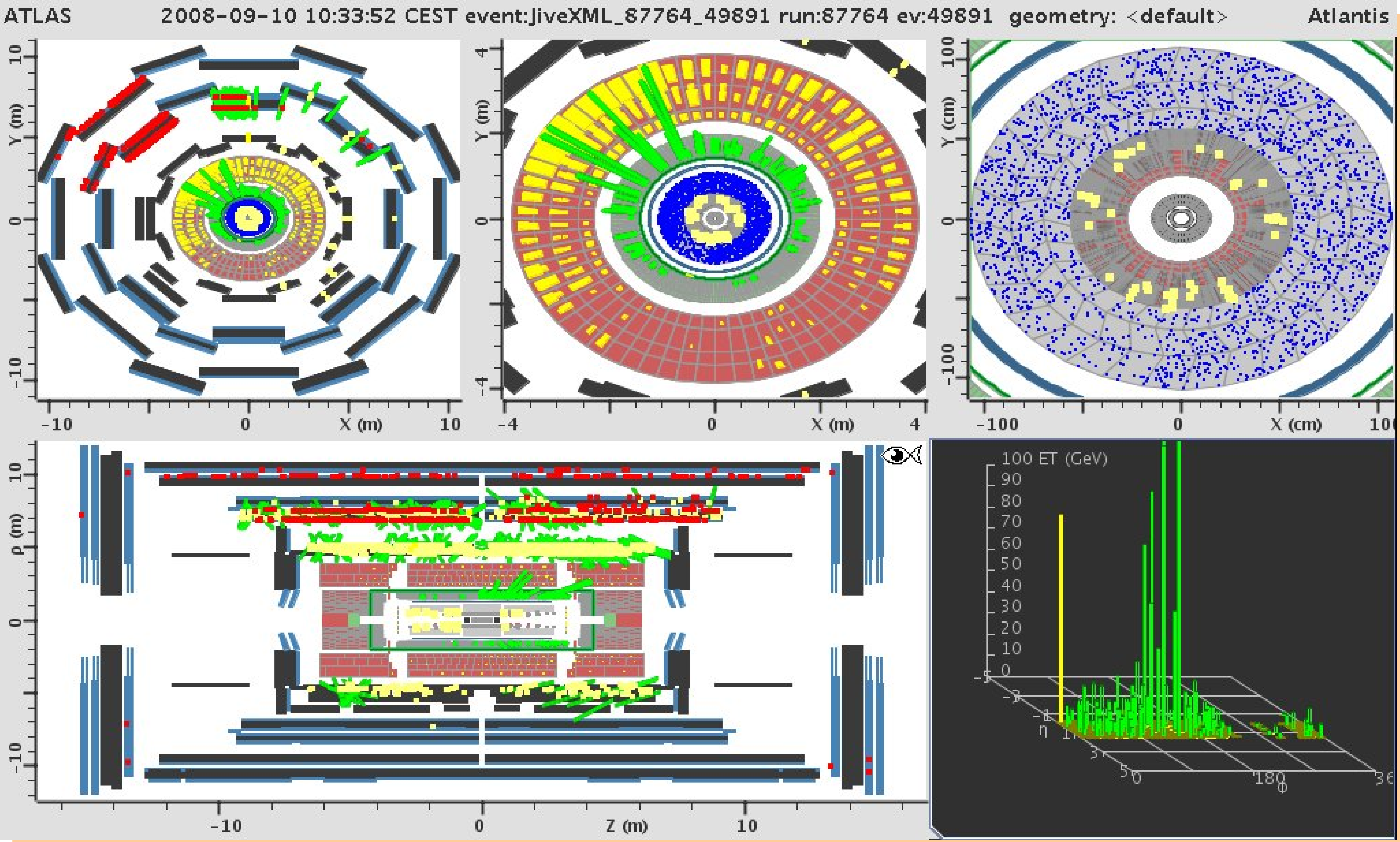
Physics issues for LHC upgrade



Outline

- Physics and integrated luminosity
- Challenging environment of High luminosity
- Critical detector components

Table 3. Physics reach for new signatures as a function of integrated L.

Integrated L (fb^{-1})	Z' TeV	$\tilde{g}$ TeV	Compositeness TeV	Highest P_T Jets TeV	Observe $H \rightarrow \mu\mu$
300	5.4	2.8	30	4.1	No
700	5.8	3.1	39	4.3	M<125 GeV
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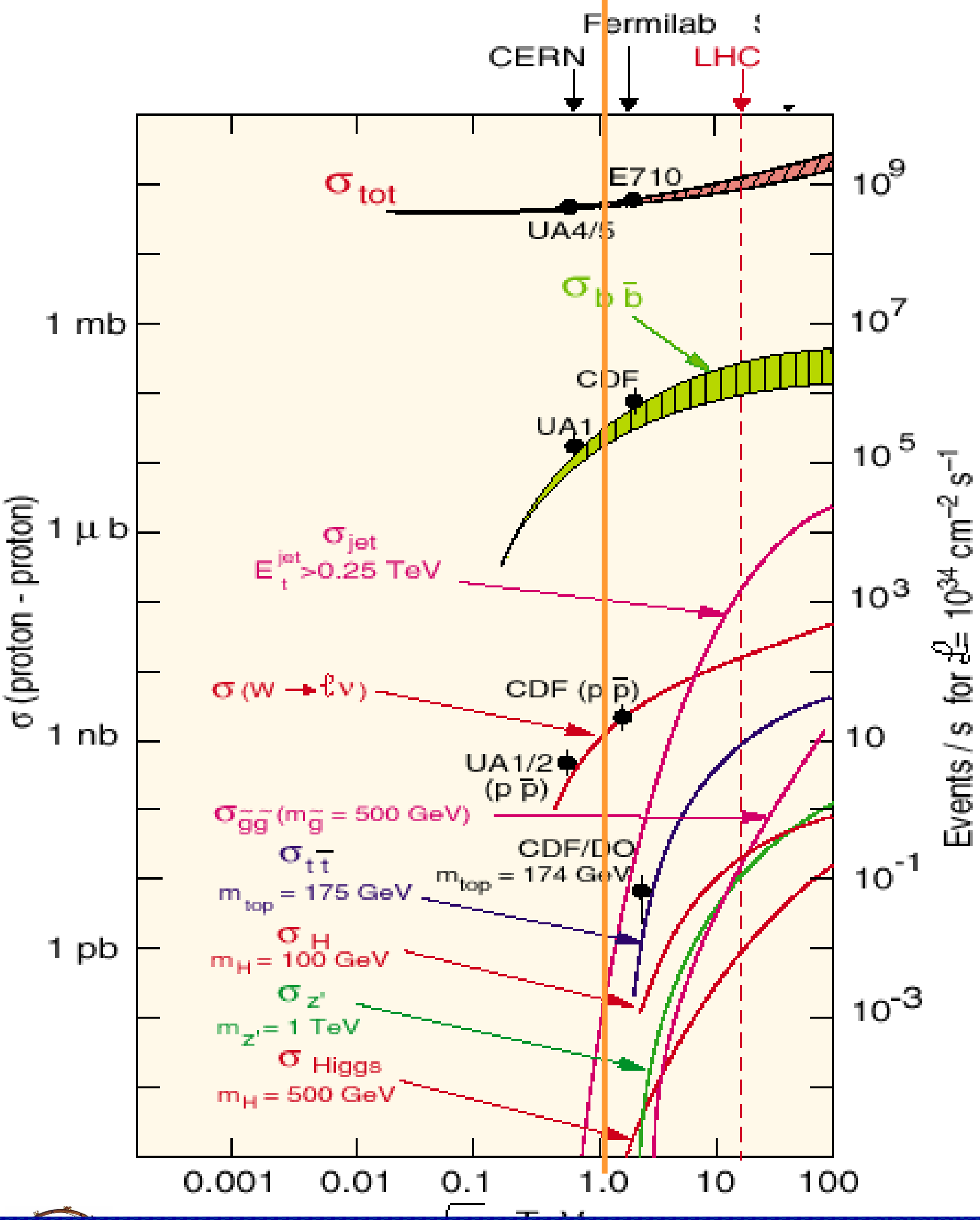
Overview of rates



- Very large dynamic range
- 100mb total rate to ~10pb for SUSY, 1 pb for Higgs
- Major challenge for trigger
  - Reduce rate while not losing physics

Physics program: enormous scope

- QCD: jets and hadronic properties
- Electroweak
  - W/Z production properties
  - Higgs discovery
- New Physics quests
  - SUSY (Dark matter?)
  - Extra dimensions
- Flavor physics
  - Top factory (~ 1Hz at 10^{33})
  - Rare B decays, Non standard CP violation in B sector
  - Flavor non conservation in tau decays
- Heavy Ions (LHC will run PbPb collisions)
- These are really facilities not experiments: expect hundreds of publications per year

Rich physics program
Many years needed
All available luminosity will be exploited

Expected evolution of physics program

- 2008/9: QCD, jets, min bias…
- 2008/2009 Standard Model W,Z, production properties
- 2008/9/10 B-physics
- 2009/2010 Top studies: decay modes. Spin, production, mass
- 2009/2010 SUSY discovery: measurements!!
- 2009/10/11 Higgs, discovery mass and properties
- Expect several hundred papers per year

Physics examples follow

Must maintain detector performance to sustain this program in longer term

Physics and integrated luminosity

- Search reach obviously increases with luminosity
  - Larger masses
    - Increases slowly as cross sections fall with mass
    - Fighting falling structure functions
    - Examples. Limits on gluinos, quark compositness
  - Final states with smaller branching ratio. (“rare decays”)
    - Rates directly proportional to luminosity
    - Examples, rare Higgs decays, rare SUSY decays
  - Luminosity increase is generally more effective for measurements than limits

Detector issues important for physics

- Heavy new objects near the limit of LHC reach
    - Triggering probably not critical as thresholds are high
- Lighter objects that need more statistics
    - May need more complex (selective) trigger strategy
- Some physics is sensitive to pile up
    - There may be 400 interactions per crossing (50ns bunches and 10^{35}): Most critical are
        - B tagging: track density degrades this
        - Jet tagging/vetoing for "low" pt jets: jet measurements degrade

Detector performance issues

- Degradation from
  - Aging
  - More radiation
  - More complex environment: pile up
- Overview of most sensitive components follows
- Investment in accelerator needs investment in detectors to maintain detector performance at higher luminosity in order to fully exploit increased statistics

Pile up: what is it and why does it matter

- Many interactions per bunch crossing:
- Number depends on bunch spacing and luminosity: 50ns and 10^{35} is 400 per crossing
  - Average effect in calorimeter similar to increased noise: But fluctuations are very differant due to jets.
- Impact is detector dependent:
  - How many bunch crossings are read out?
- Detailed simulation is incomplete
  - Most sensitive for Low PT physics
  - Considerable uncertainties in properties of pile up (min bias) events (factor of 2 in transverse energy)
  - 2008 data will provide vital information

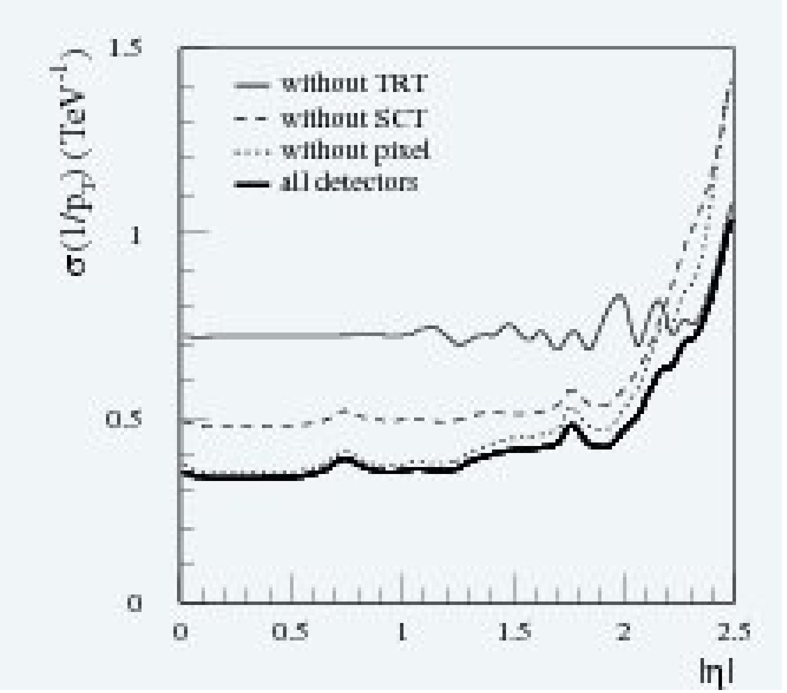
Importance of detector components: Pixels

- Inner (b-) layer vital for identification of b-jets
  - Vital in B-physics
  - Top quark studies: reject backgrounds
  - New physics
    - Need to distinguish decays to different (quark) final states
    - May favor decays to b (SUSY, Higgs)
    - S/B may be better in final state with B's

Importance of detector components: TRT

- Contributes to
  - Pattern recognition
  - Only 7 points per track from SCT/Pixels without TRT
  - Most critical in dense environment
    - Inside jets or with pile up at higher luminosity
- Momentum resolution without outer tracker

Pions (e.g. from tau): resolution degrades by factor of two

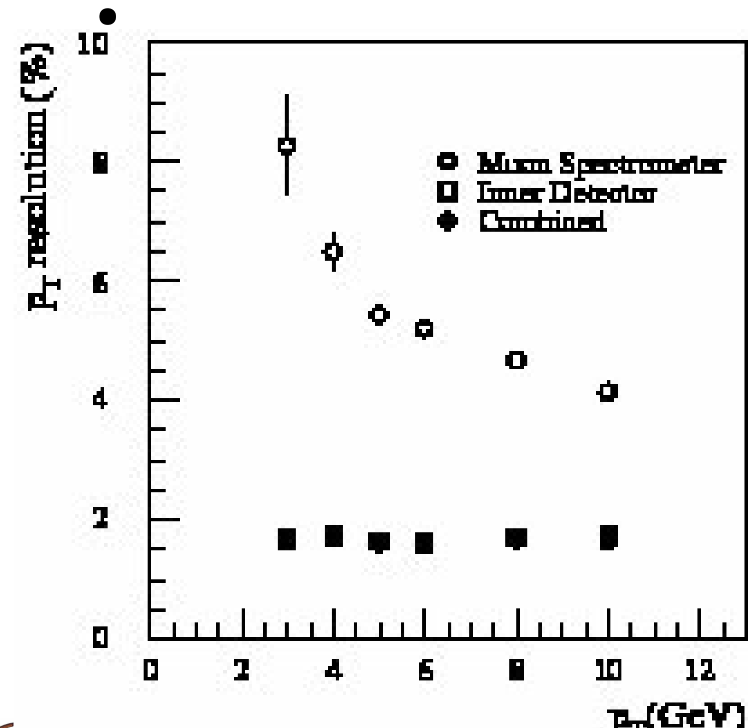


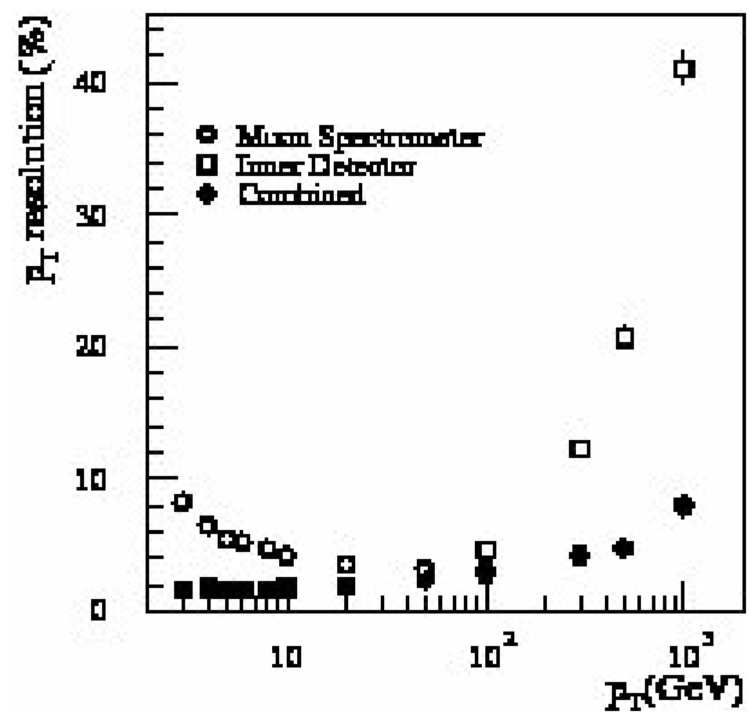
Importance of detector components: TRT

- Momentum resolution without outer tracker
  - Electrons
    - charge (sign) measurement compromised at high pt (10% probability of wrong sign at 1 TeV)
      - Note that energy measurement is dominated by calorimeter
      - TR (transition radiation) function provides e/pi separation

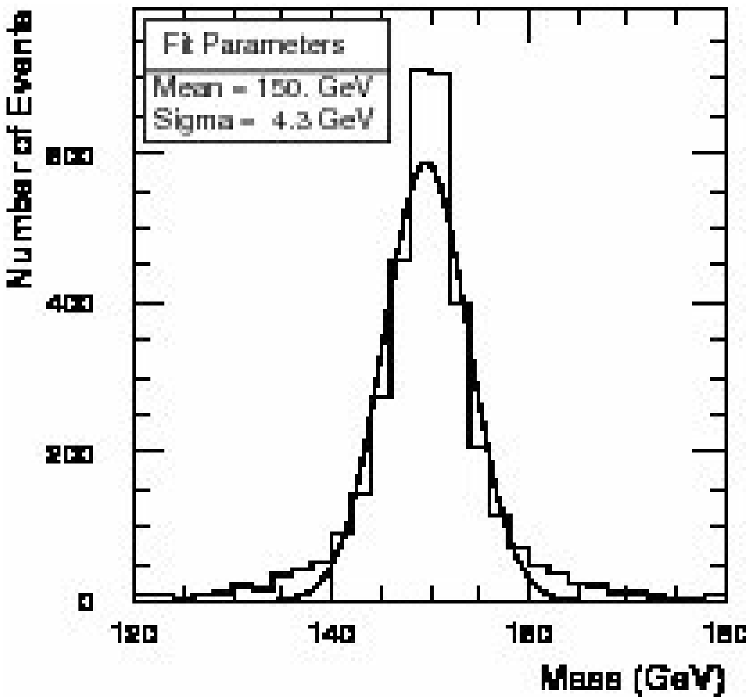
Importance of detector components: TRT

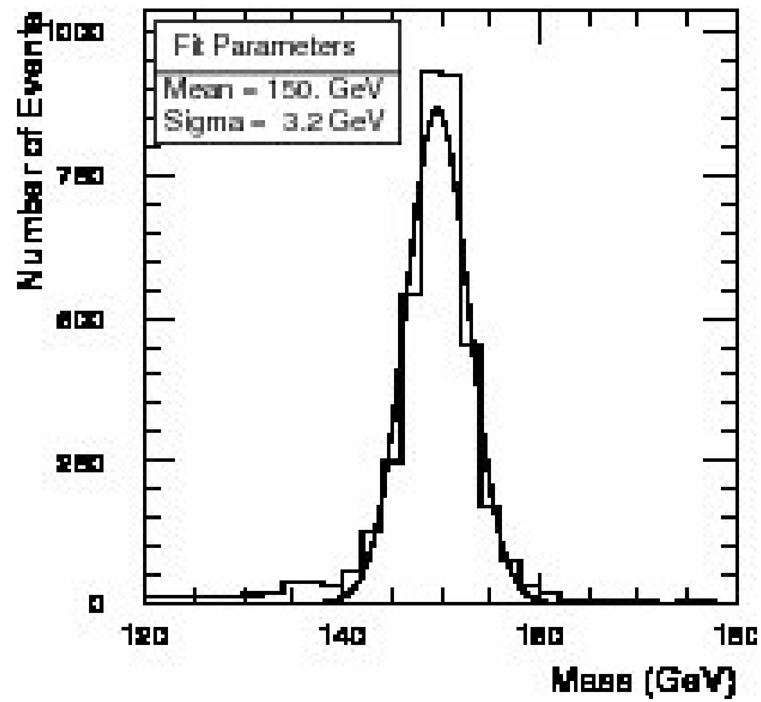
- Momentum resolution without outer tracker
  - Muons at low pt
    - Combination of muon system and ID: Muon system at high Pt, tracker at lower pt. No TRT: resolution factor of two worse at low pt





Muon resolution: physics impact





Muons system alone

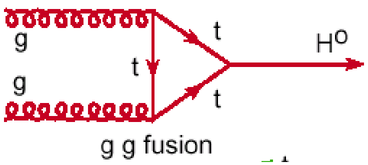
Combined

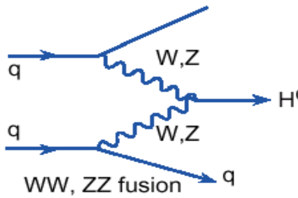
150 GeV resonance: See Higgs example later

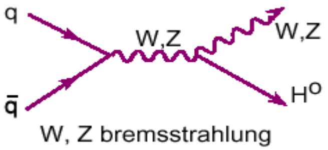
Importance of detector components: Forward calorimeter

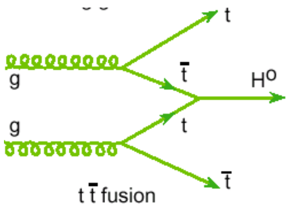
- Missing ET
  - Resolution degrades by factor of two without FCAL
  - At 10**35, expect 80 GeV of ET miss in every event with no FCAL
  - New physics, SUSY, Higgs compromised
- Forward Jet tagging
  - Indispensable if Higgs is light
    - Some final states cannot be seen at all
  - or Higgs is very heavy
    - Background cannot be rejected

Higgs on one slide

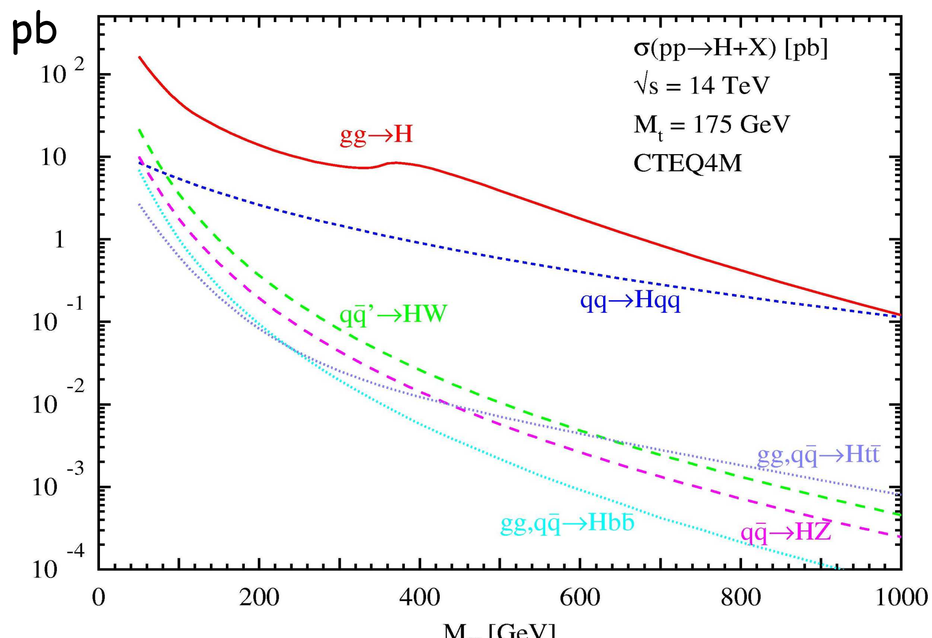


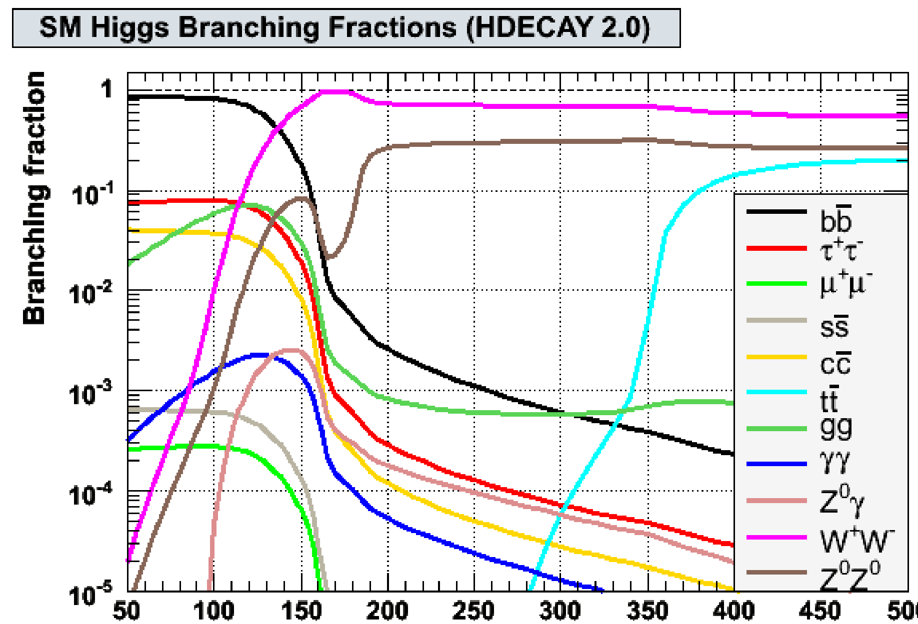






Needs FCAL!!





m_H < 130 GeV : $H \to$ bb, $\tau\tau$ dominate

Best channels at LHC: $qqH \to qq\tau\tau$, $ttH \to lbbX$, $H \to \gamma\gamma$

m_H > 130 GeV : $H \to WW^{(*)}, ZZ^{(*)}$ dominate

best search channels at LHC: $H \to ZZ^{(*)} \to 4l$ (gold-plated), $H \to WW^{(*)} \to l\nu\ l\nu$

Extending searches I: Rare Higgs decays

- H to Z gamma marginal with LHC if M(H) 120-160 GeV
  - 300 inverse fb yields 3 sigma in (ee or $\mu\mu$)+gamma (2.5 fb cross section) (130 GeV)
    - Not limited by trigger
    - Does not need jet tagging or veto
  - Would be clearly seen and measured with SLHC (11σ)
- Higgs to μ μ: no trigger or jet issue: Clean observation

m_H (GeV)	$S/\sqrt{B}$	$\frac{\delta\sigma \times BR(H\to\mu\mu)}{\sigma \times BR}$
120 GeV	7.9	0.13
130 GeV	7.1	0.14
140 GeV	5.1	0.20
150 GeV	2.8	0.36

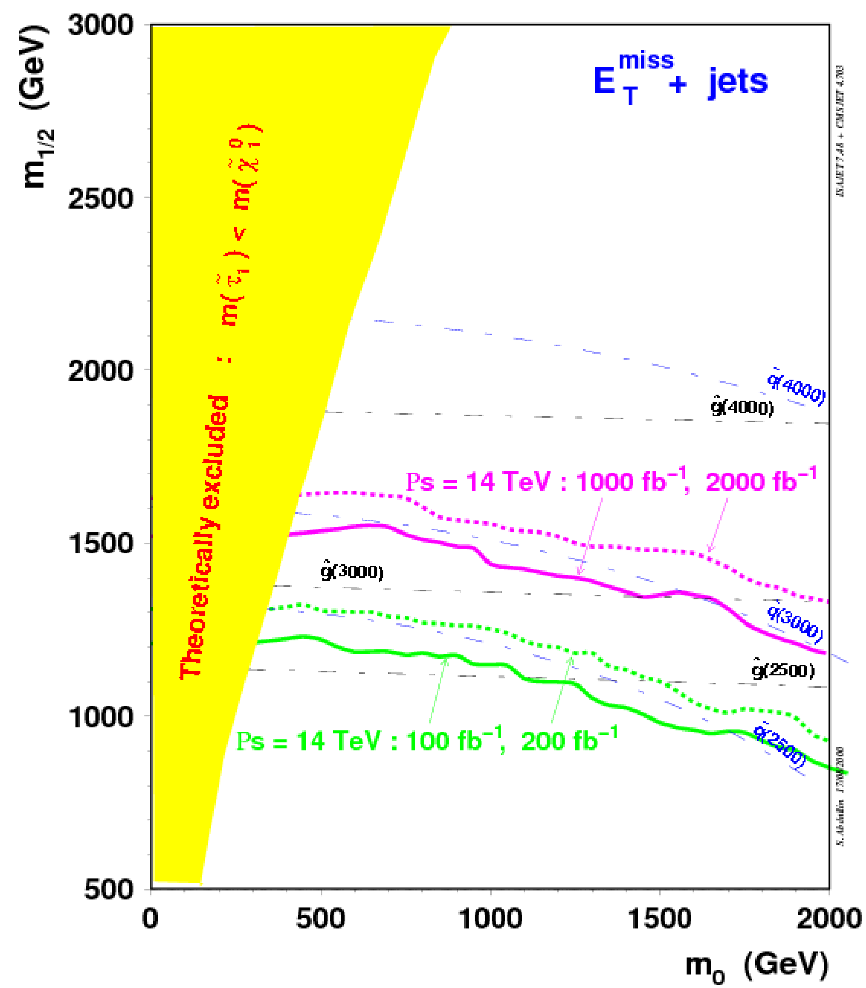
Note that resolution must be persevered or signal degrades

3000 inverse femtobarns

Search II: Physics reach for SUSY

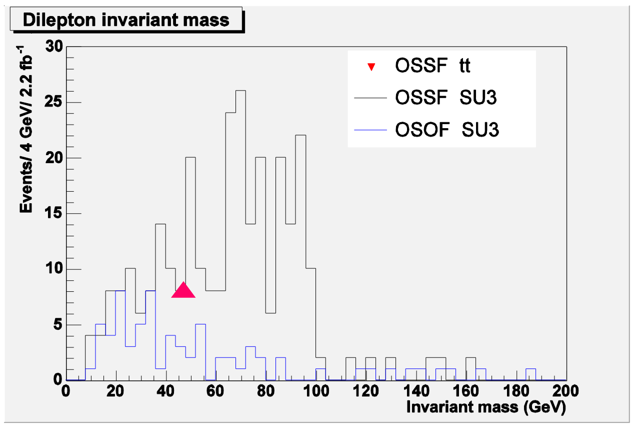
Time period	Luminosity [cm^{-2}s^{-1}]	squark/gluino masses
1 month	10^{33}	~1.3 TeV
1 year	10^{33}	~1.8 TeV
1 year	10^{34}	~2.5 TeV
Ultimate	$\int$ = 300 fb^{-1}	~2.5–3 TeV
D0 & CDF	$\int$ = 0.3 fb^{-1}	$>_{(2\sigma)}$ 0.35 TeV

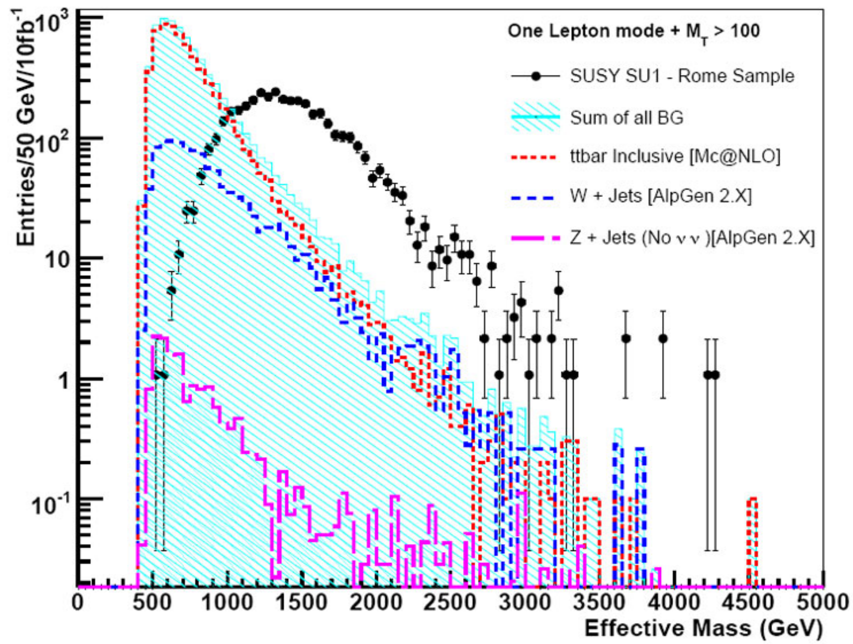
5σ discovery reach for SUSY:



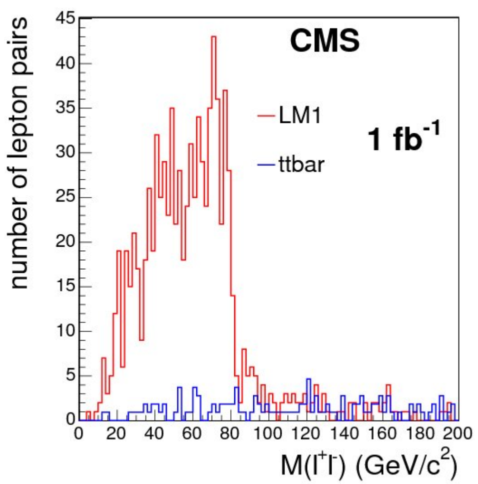
Inclusive measurements: critically dependent on missing ET, leptons and jets

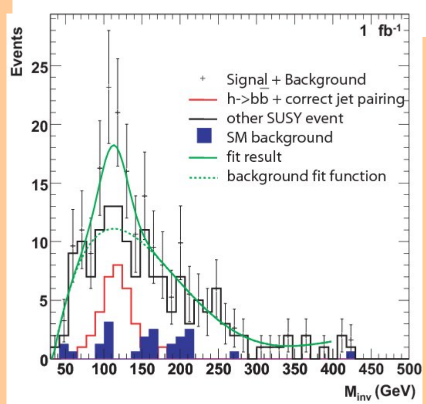
LHC →The Bevatrino: masses and couplings

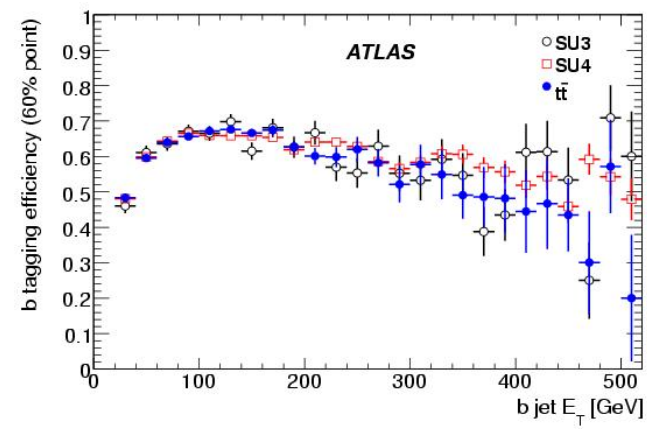




This program would never be finished







Give me 2hrs and I'll explain these!

Search III: Physics reach increases with luminosity

Table shows a few examples:

Note that constant detector performance is assumed

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Measurement limited by statistics Higgs: strongly coupled WW

If there is no light Higgs then, WW scattering becomes “strong” at high energies

Rate limited counting experiment: study ZZ,ZW and WW final states. May not be any “peaks”

Expect to establish signal at LHC (2012??)

But not easy to constrain underlying physics

Rate limited: will need more data to get minimal understanding of underlying mechanism

<u>Will not work without jet tagging provided by the FCAL</u>

Measurement limited by statistics
Higgs: strongly coupled WW

Table 2: Expected numbers of reconstructed events above an invariant mass of 600 GeV (for $\sqrt{s}$ =14 TeV) for models with a strongly-coupled Higgs sector and for the background. The significance was computed as $S/\sqrt{S+B}$.

Model	300 fb^{-1} 14 TeV	3000 fb^{-1} 14 TeV
Background	7.9	44
K-matrix Unitarization Significance	14 3.0	87 7.6
Higgs, 1 TeV Significance	7.2 1.8	42 4.5

Conclusions

Luminosity upgrade provides extended LHC physics program.
More pay-off from LHC investment

Ensures continuing frontier physics

Detector performance must not degrade

Need to start now if we are to be ready in time

Backup

Critical issue #I: low pt jets

- Important as tool for cleaning up S/B in some processes
  - Direct production of new electroweak objects: Example SUSY winos
    - Less QCD radiation means “quiet” environment
    - Backgrounds often come from strong interacting things such as top
      - More QCD radiation
    - Vetoing events with low pt jets can help S/B
  - Higgs via VBF: qq to qqH
    - Needed to measure some final states such as tau tau at low mass
    - Provides more information on Higgs couplings
    - Need to extract this
    - Signal has two forward jets and “quiet” central region
    - Background is QCD: lots of jets flat in rapidity
    - S/B enhanced by presence for forward jets and absence of central jets
- More pileup can make jets from pileup and raise pt of existing jets
  - Makes both vetoing and tagging less effective

Critical issue #2 b-tagging

- No reason to expect significant degradation of performance for **isolated** high pt tracks:
  - Assume same as current detector for e and mu with pt>20 GeV: studies gave few per cent degredation
- Btagging is harder
  - High pt is in dense environment: pileup makes it worse
  - Low pt depends on soft tracks: pileup makes it worse
  - May be needed for Higgs physics and SUSY measurements

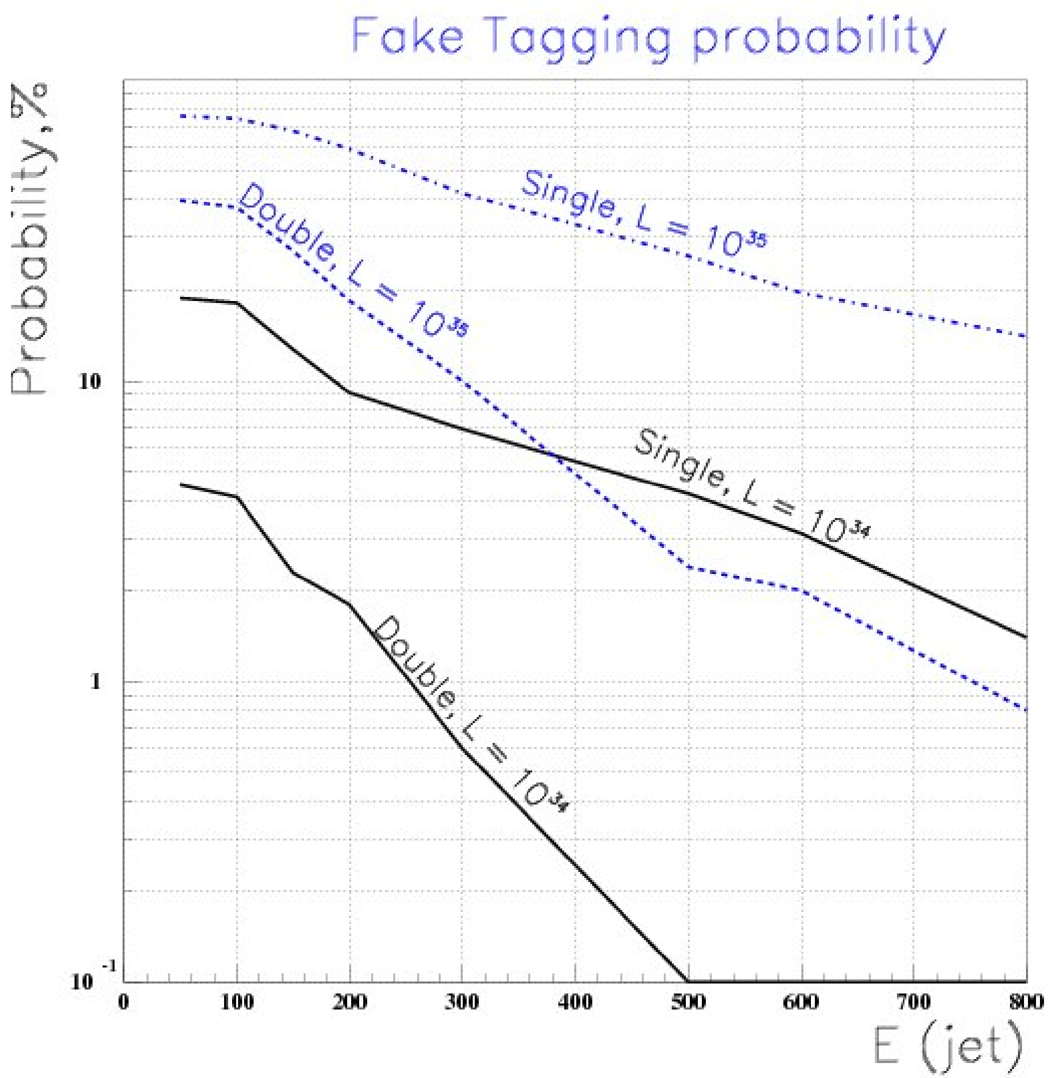
Table 1: Rejection against u-jets (R_u) for a b-tagging efficiency of 50% and in various p_T-bins, as expected in ATLAS at the LHC design luminosity and with the upgraded luminosity.

p_T (GeV)	R_u at 10^{34} cm^{-2}s^{-1}	R_u at 10^{35} cm^{-2}s^{-1}
30-45	33	3.7
45-60	140	23
60-100	190	27
100-200	300	113
200-350	90	42

Based on 100 events/crossing: too optimistic!

Critical issue #2: low pt jets

- Jets from "garbage"



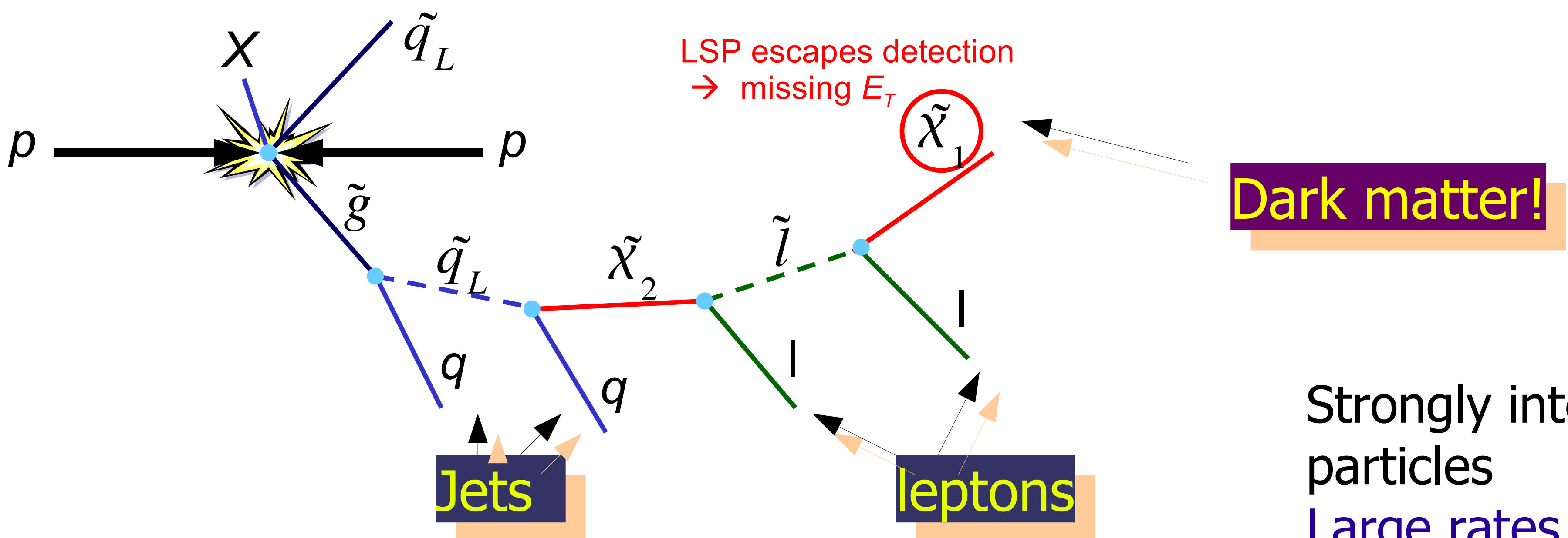
Look for 1 or two jets
at abs(eta)>2

Cone of 0.4 used

Very large fraction of
event will have single tag

SUSY: phenomenology in one page

- Conserved ***R*-parity** requires existence of a **lightest stable SUSY particle (LSP)**. Since no exotic strong or EM bound states (isotopes) have been observed, the LSP should be neutral and colourless **WIMP:** LSP signature just as heavy neutrino
- The LSP is typically found to be a spin- **neutralino**, a linear combination of gauginos (in much of the SUSY parameter space the neutralino is a mixture of photino and zino)
- With *R*-parity: **SUSY** production in **pairs requires energy 2 > SUSY mass** !



Strongly interacting particles
Large rates

"Typical" SUSY decay chain at the LHC